

# ANTHROPOGENIC AND VOLCANIC CONTRIBUTIONS TO THE DECADEAL VARIATIONS OF AEROSOLS IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE

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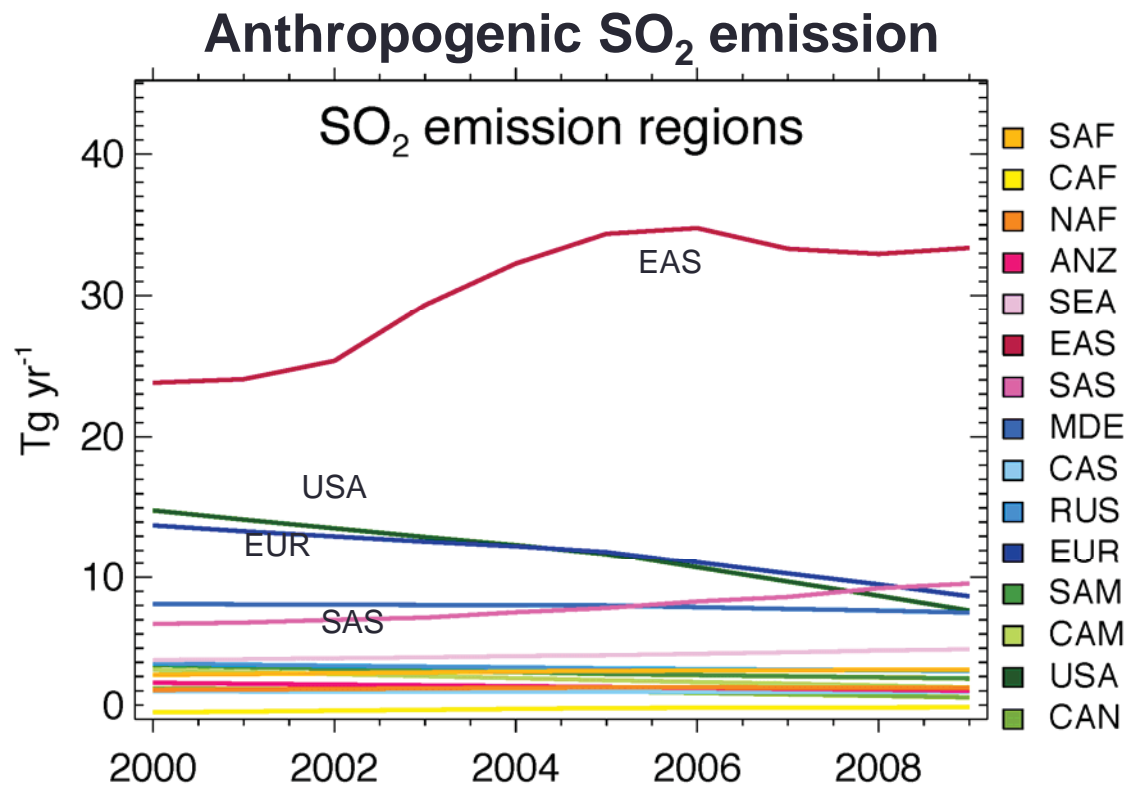
# Introduction

- The origin and variability of stratospheric aerosol have drawn considerable attention because the change of such aerosol could have long-term climate effects
- Recent observations seem to suggest that the stratospheric aerosol has been increasing in the past decade without major volcanic eruptions
  - It was suggested that the increase of Asian anthropogenic emission was the cause of such an increase (Hofmann et al., 2009)
  - But other studies showed that small-to-medium volcanic emission trends in the past decade can explain the stratospheric aerosol changes (e.g., Vernier et al., 2011; Neely et al., 2013)

# This study

- We compare the GOCART model simulation (1.25°longitude x 1°latitude, 72 layers) of SO<sub>2</sub> and aerosols with satellite observations from OMI, MLS, SCIAMACHY, and CALIPSO in UTLS
- We use the model results to assess the relative contributions of volcanic and anthropogenic emissions to the decadal variations of UTLS aerosols

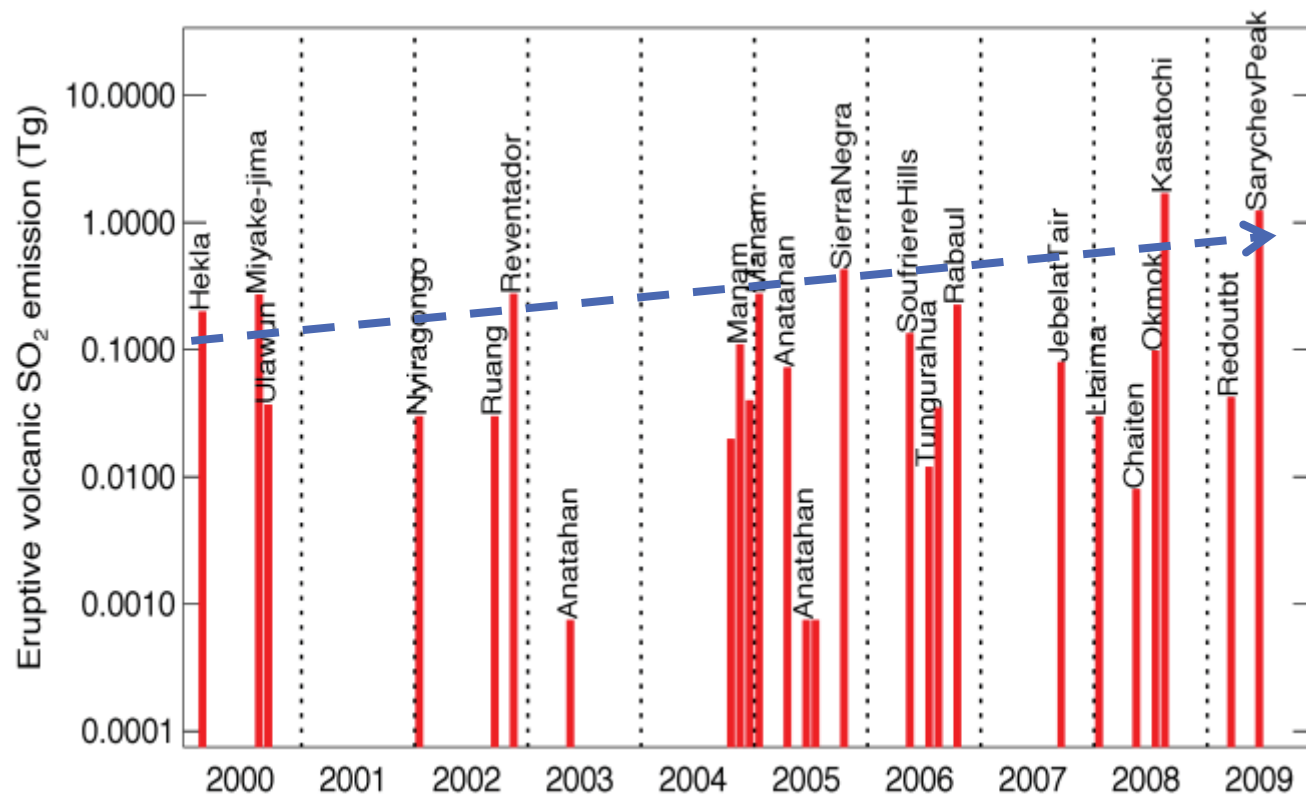
# Anthropogenic SO<sub>2</sub> emission, 2000-2009



Emission data from: Z. Lu, D. Streets, et al., 2010;  
Diehl et al., 2012

- Anthropogenic SO<sub>2</sub> emissions in East Asia and South Asia have increased significantly in the last decade
- In the meantime anthropogenic emission has decreased significantly in US and Europe
- The question is: How efficient the transport is to lift Asia surface pollution to the stratosphere to control the stratospheric aerosol trend?

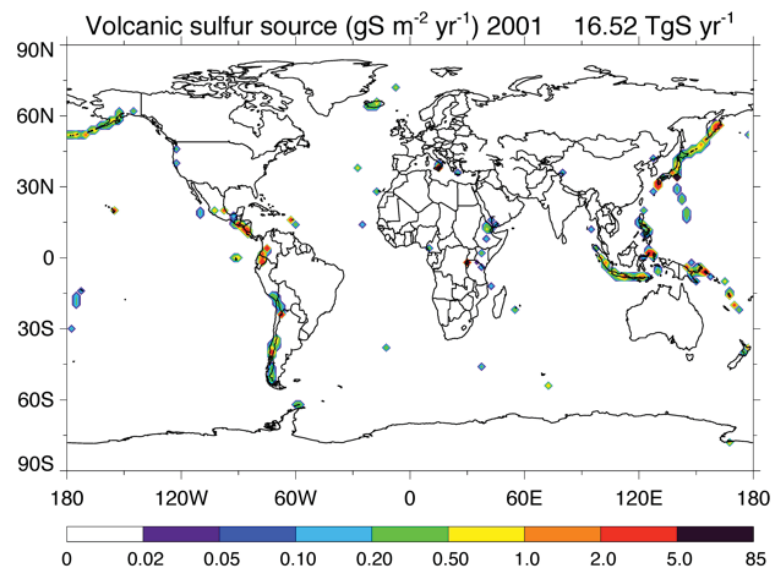
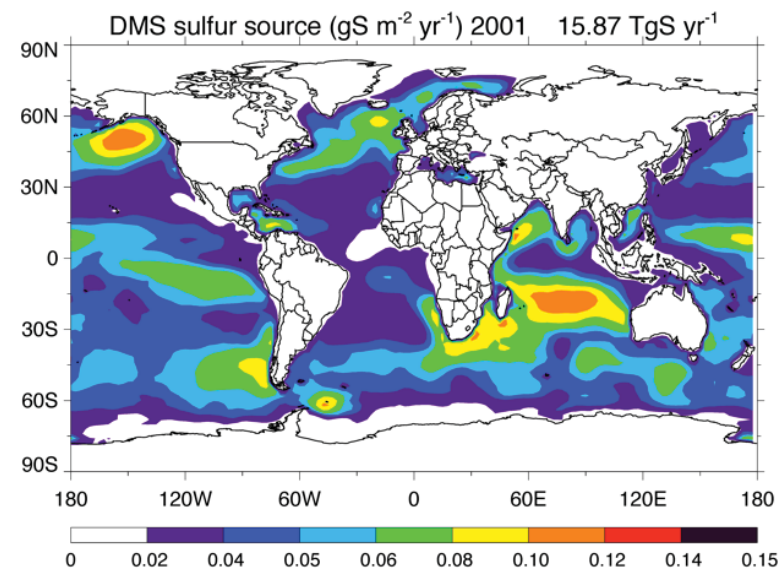
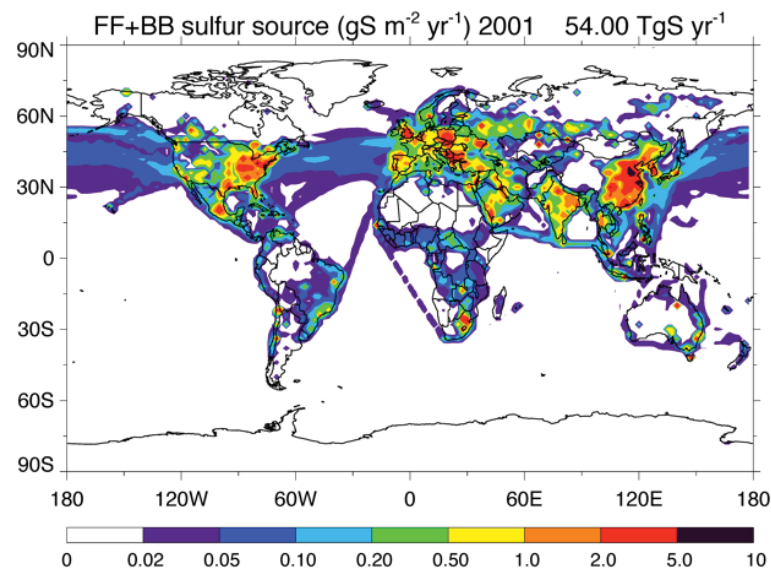
# Volcanic emission of SO<sub>2</sub> going to the UTLS, 2000-2009



- Volcanic emissions that reach the UTLS seem to have a positive trend as well
- And they release SO<sub>2</sub> at high altitudes to have a more direct influence than Asian anthropogenic sources

SO<sub>2</sub> emission from eruptive volcanoes from 2000 to 2009 with injection height above 10 km. Data source: OMI, GVP, and in-situ measurements reported in literature (Diehl et al., 2012)

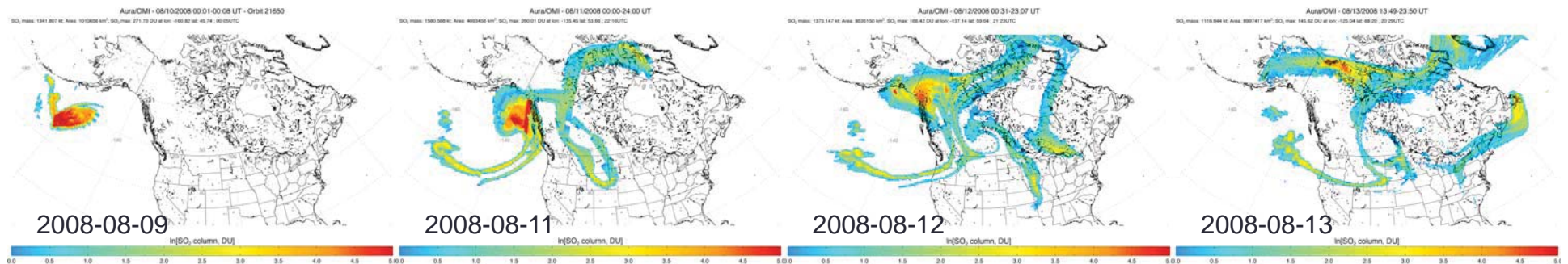
# Global SO<sub>2</sub> emissions, 2001



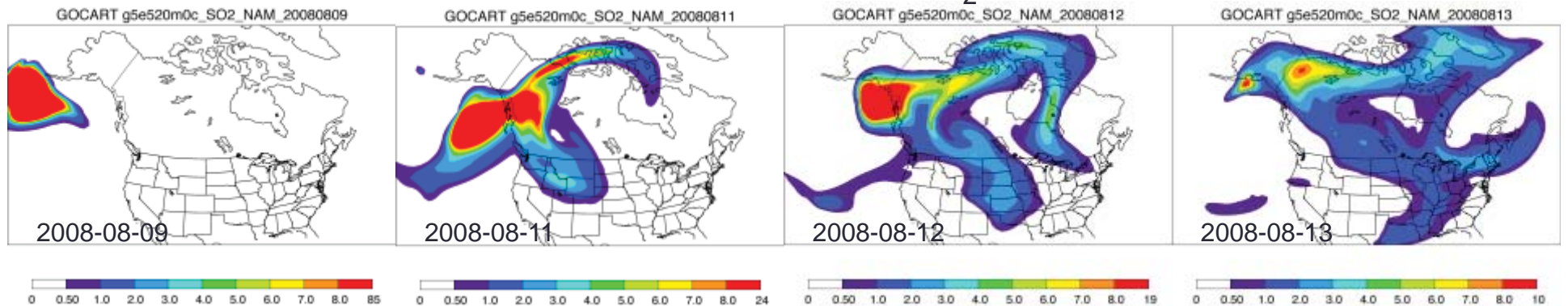
(Note: stratospheric background aerosol from OCS oxidation has recently been implemented but is not included in this presentation)

# Volcanic SO<sub>2</sub> – Kasatochi, Aug 2008

## OMI column SO<sub>2</sub>



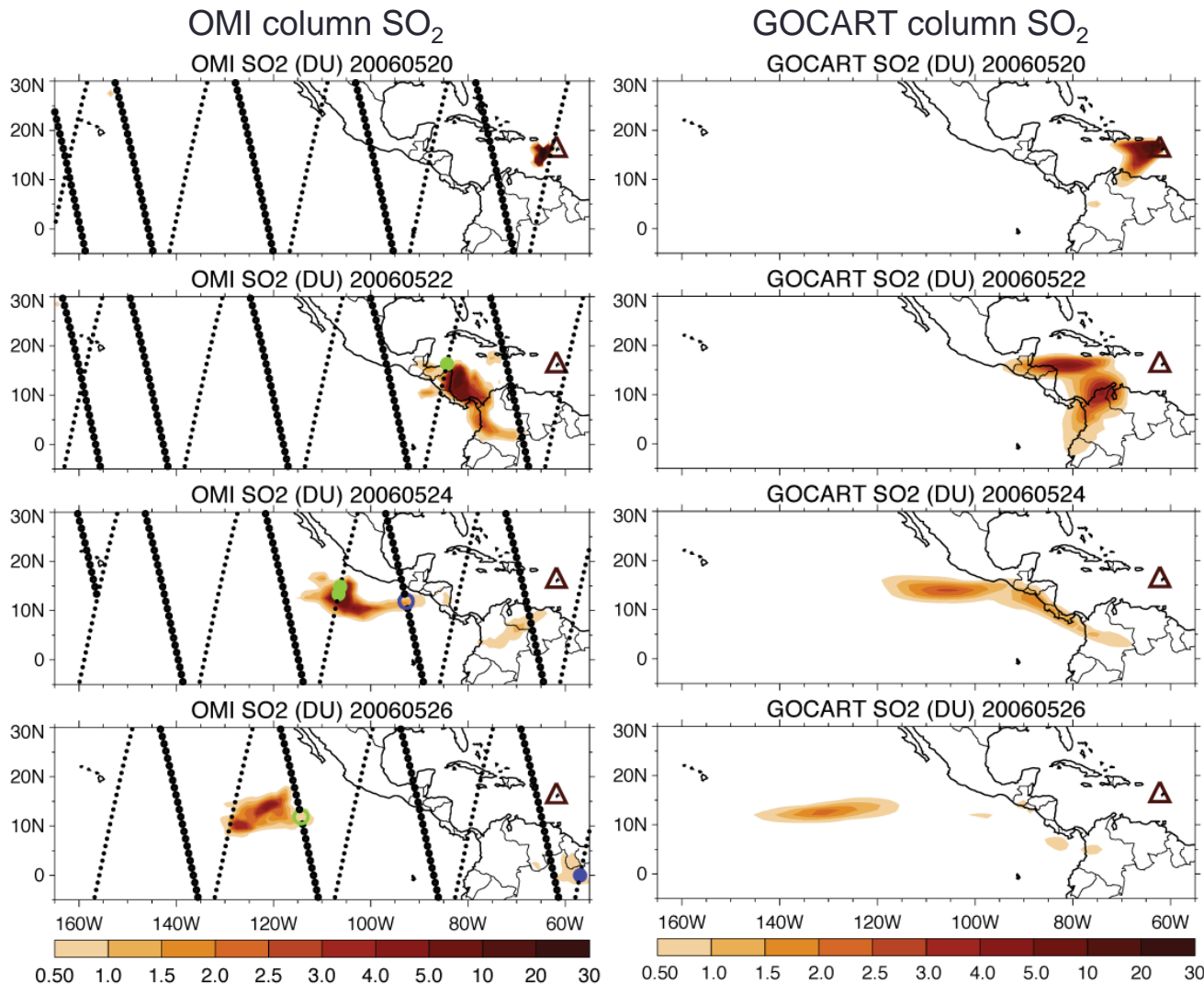
## GOCART column SO<sub>2</sub>



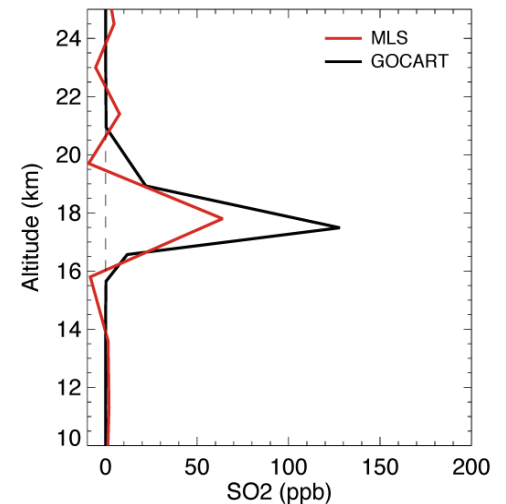
OMI: snapshot at ~1:40 pm local time GOCART: daily average  
(note: unit and color scales are different between OMI and GOCART)



# Volcanic SO<sub>2</sub> - Soufrière Hills, May 2006



SO<sub>2</sub> vertical profile,  
MLS vs GOCART



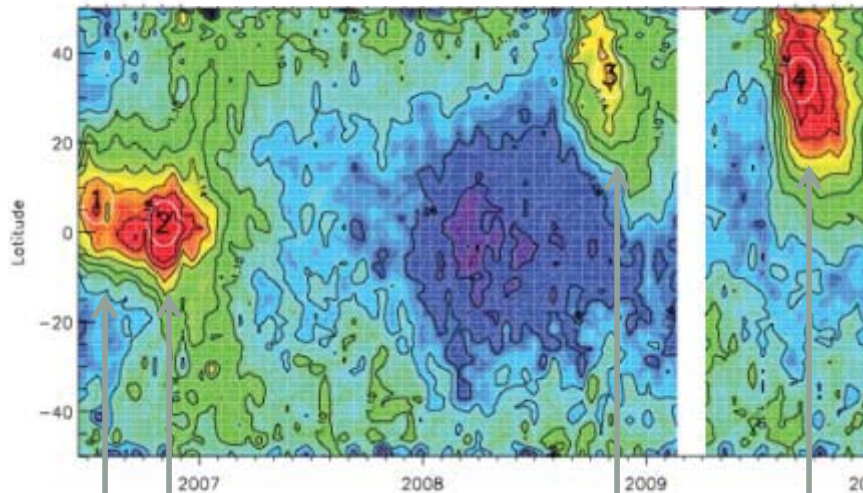
GOCART seems to capture the volcanic plume movement and height, although it is a little more diffusive

Time series of Soufrière Hills on the Caribbean island of Montserrat (16.7°N, 62.2°W, location shown in triangle) volcanic SO<sub>2</sub> plume (in Dobson Unit) from OMI (left column) and GOCART (right column). Superimposed on the OMI panels are the MLS daytime (large black circles) and nighttime (small black circles) tracks. Locations where stratospheric SO<sub>2</sub> level is greater than 30 ppb as seen by MLS are indicated in large circles: Green at ~70 hPa altitude (open circle daytime, closed circle nighttime), blue at ~100 hPa,



# Comparison with CALIPSO

CALIPSO aerosol 17-21 km (SR)

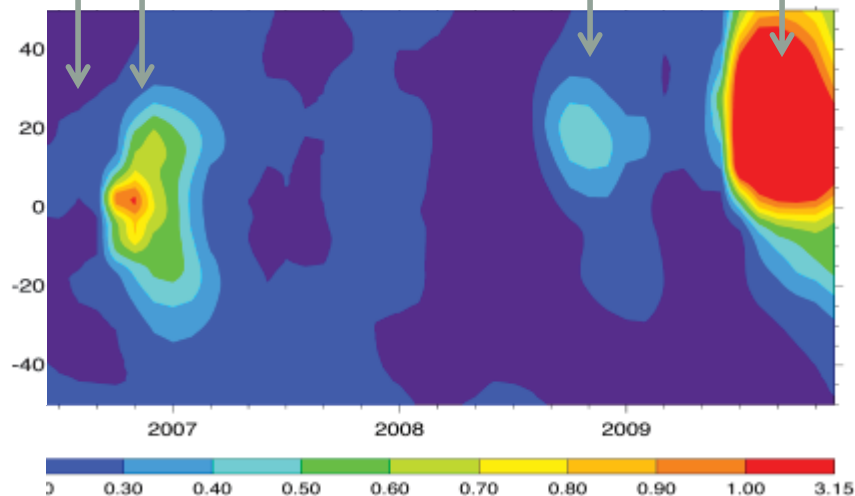


## Volcanic eruptions:

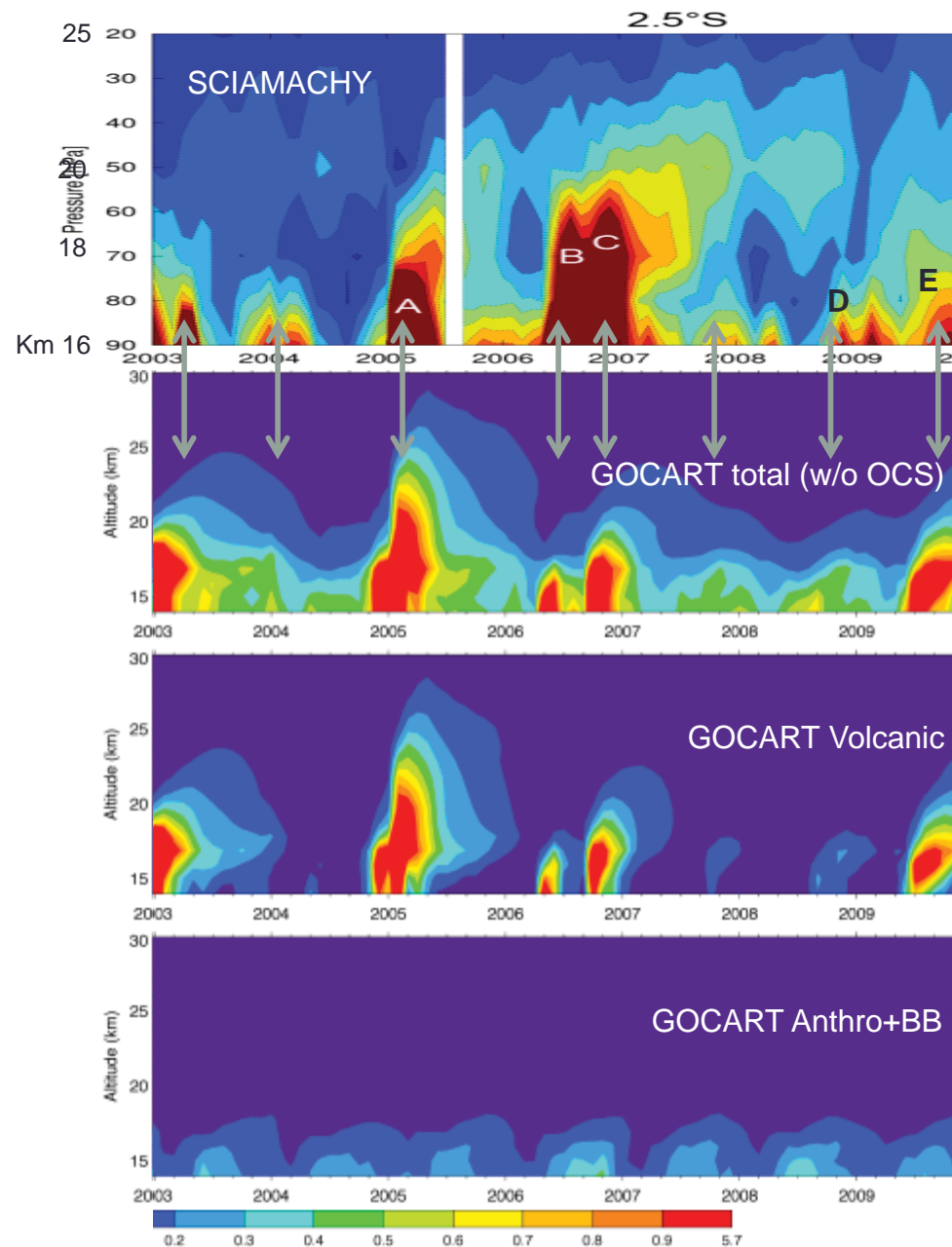
1. Soufriere Hills (May 2006, 16°N)
2. Tavurvur (Oct 2006, 4°S)
3. Kasatochi (Aug 2008, 52°N)
4. Sarychev Peak (July 2009, 48°N)

(Figure from Solomon et al., 2011)

GOCCART aerosol ~18-20 km (extinction  $\text{Mm}^{-1}$ )



Injection height of some volcanoes could be inaccurate in the model



## Comparisons with SCIAMACHY aerosol extinction profiles at 2.5S

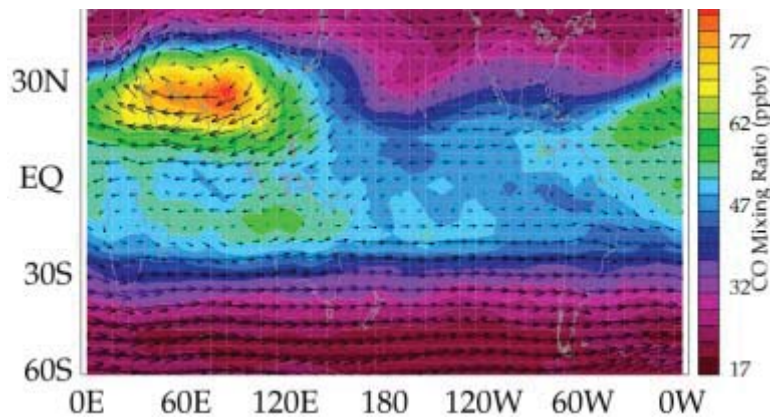
(SCIA figure from John Burrows)

### Volcanic eruptions:

- A) Manam (Jan 2005, 4°S)
- B) Soufriere Hills (May 2006, 16°N)
- C) Tavorvur (Oct 2006, 4°S)
- D) Kasatochi (Aug 2008, 52°N)
- E) Sarychev Peak (July 2009, 48°N)

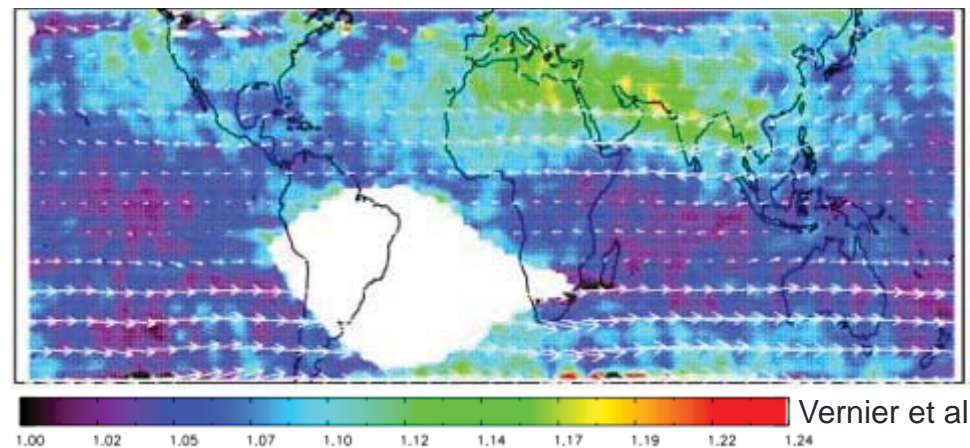
# Transport of pollution to the UTLS

MLS CO (ppbv) Jul-Aug 2005 100 hPa



Park et al., 2007

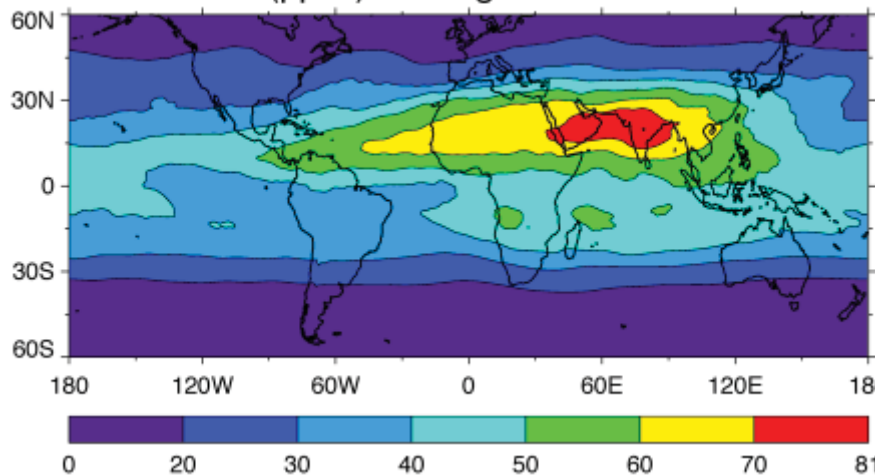
CALIOP aerosol SR (532 nm) Jul-Aug 2008 15-17 km



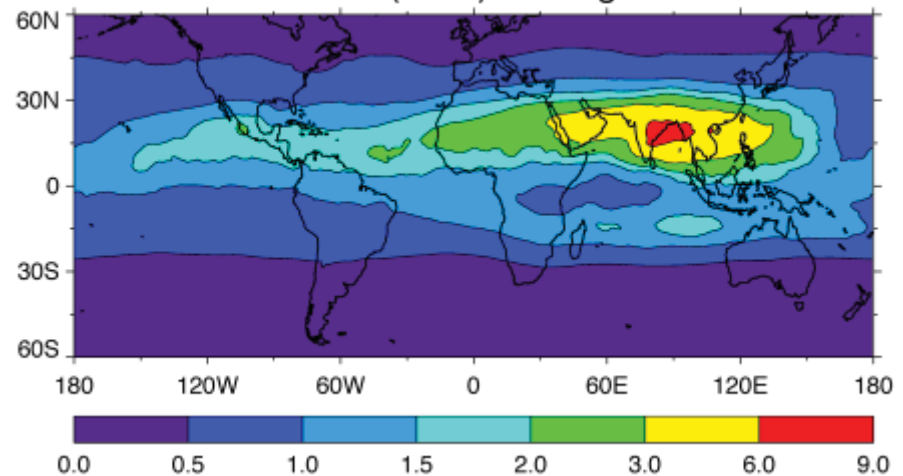
Vernier et al., 2011

GEOS-5/GOCART simulations

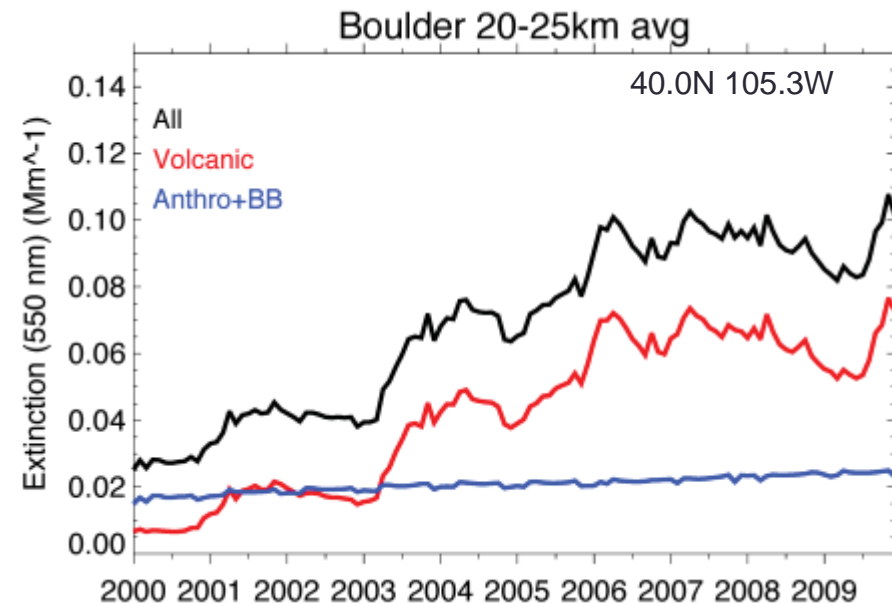
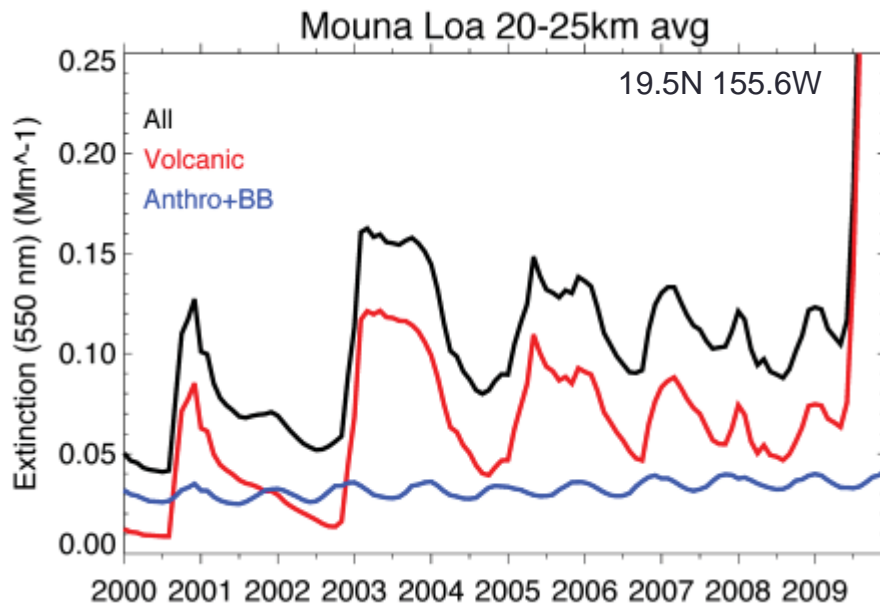
CO (ppbv) Jul-Aug 2008 100 hPa



Aerosol extinction ( $\text{Mm}^{-1}$ ) Jul-Aug 2008 100hPa



# Attribution of “trends” (GOCART)



- Clearly, variations and trends are different in different locations
- The anthropogenic sources impose an organized, smooth change in the lower stratosphere
- The numerous volcanic eruptions frequently perturb the “background”, or even showing an increase trends over certain locations
- On average, volcanic aerosol is nearly 2x as much as anthropogenic aerosols in the stratosphere ( $> 16 \text{ km}$ , 50S-50N) from 2000 to 2009

# Conclusions

- Both satellite data and model have shown that even without major explosive volcanic eruptions, volcanic emissions frequently perturb the stratospheric “background” aerosols, making it difficult to define non-volcanic background aerosol values in the stratosphere
- Although the ratio of volcanic/anthropogenic SO<sub>2</sub> emission is only 1:4 on decadal average (2000-2009), the ratio of corresponding stratospheric amount is disproportionally 2:1, due to the high altitude emissions from volcanoes
- The increase of anthropogenic emissions in Asia does seem to contribute to the increasing trend of stratospheric aerosol with well organized seasonal variations, but the most influence is confined in the UT
- The model suggests that the volcanic sources could be more responsible than the anthropogenic sources for the apparent increasing trend of stratospheric aerosol in the past decade, and the trends are location-dependent



# Work in progress (Aura project)

- Using OMI and MISR data to obtain the emission amount and injection height of volcanic and PyroCb biomass burning emissions
- Incorporating stratospheric background sulfate aerosol production from OCS oxidation
- Using satellite datasets from OMI, MLS, as well as other satellite data from OSIRIS, MIPAS, SCIAMACHY, and CALIOP, aircraft data from HPPO and CARIBIC, and ground-based lidar data to deduce the origins and processes forming UTLS aerosols
- Deducing seasonal and decadal variations and trends of UTLS aerosols in different regions and estimating the climate effects of UTLS aerosols